Utilities Policy 53 (2018) 94–101

Contents lists available at ScienceDirect

Utilities Policy

journal homepage: www.elsevier.com/locate/jup

Dimensions of energy security in Small Island Developing States

Pravesh Raghoo[a], Dinesh Surroop[a,*], Franziska Wolf[b], Walter Leal Filho[b,c], Pratima Jeetah[a], Bernd Delakowitz[d]

[a] University of Mauritius, Department of Chemical and Environmental Engineering, Réduit, 80837, Mauritius
[b] Hamburg University of Applied Sciences, Research and Transfer Centre Sustainability and Climate Change Management, Ulmenliet 20, 21033, Hamburg, Germany
[c] Manchester Metropolitan University, School of Science and the Environment, Manchester Metropolitan University, Chester Street, Manchester, M1 5GD, UK
[d] University of Applied Sciences Zittau/Görlitz, Institute for Ecology and Environmental Protection, Theodore-Körner-Allee 16, 02763, Zittau, Germany

ARTICLE INFO

Keywords:
Small Islands Developing States (SIDS)
Energy security
Strategies

ABSTRACT

For Small Island Developing States (SIDS) that import oil, energy security is very important and dealt with seriously. This paper attempts to fill a gap in the literature by identifying the dimensions that shape a secure and sustainable supply of energy in SIDS. Seven dimensions were identified and incorporated into a framework for conceptualising and assessing SIDS energy security which are: import dependency; energy prices; climate change and resilience; governance; infrastructure; equity; and energy efficiency. This study also recommends selected strategies and actions to improve energy security in SIDS.

1. Introduction

Energy security has been broadly defined in the scientific literature (Ebinger, 2011). While some have conceptualised energy security relative to economic development, others see energy security in terms of energy availability, resource affordability, environmental sustainability, energy efficiency, and technology (APERC, 2007; Lefèvre, 2010; Sovacool and Mukherjee, 2011; Cao and Bluth, 2012; Hughes, 2012; Chuang and Ma, 2013; Selvakkumaran and Limmeechokchai, 2013; Martchamadol and Kumar, 2013; Misila et al., 2015; Phdungsilp, 2015). Kucharski and Unesaki (2015) supported Winzer (2012) and Leal Filho and Voudouris (2013), who stated that energy security is concerned about risks and vulnerabilities whether caused by geopolitical events or natural disasters. Cherp and Jewell (2011) discussed robustness, sovereignty, and resilience as three aspects of energy security. Chester (2010) discussed the polysemous nature of energy security, critiquing the often vague, elusive, inherently difficult, abstracted, and blurred concepts of energy security in the literature. Rosen (2009) looked at the key energy-related steps in addressing climate change.

While it is widely agreed that 'energy' refers to both primary (oil, coal, natural gas, and renewable energy) and secondary sources (electricity), numerous studies in the literature on energy security focus predominantly on the reliability of oil supply (Vivoda, 2010; Stringer, 2008). This is probably because oil is the most consumed primary energy resource in the world, accounting nearly 33% of the global energy market (BP, 2016; Vivoda, 2010), and because oil prices often fluctuate as a result of political instability and conflicts in major oil producing countries (Asif and Muneer, 2007). Volatile oil prices have negative repercussions on both oil exporters (as they are faced with varying revenues) and oil importers as they perceive significant uncertainty about imports costs and fuel subsidies. In this context, several studies were conducted to better understand, define and characterise the broad concept of energy security (Rentschler, 2013; Narula and Reddy, 2016).

Policymakers often measure energy security through energy indicators and indices derived from suitable dimensions or assessment instruments, which are factors that influence a stable energy supply in a country (Narula and Reddy, 2015). Hence, Vivoda (2010) proposed 11 dimensions and several attributes to gauge energy performance, Sovacool (2011) presented 20 dimensions. von Hippel et al. (2011) provided six dimensions and numerous attributes and strategies to characterise energy security performance. A number of authors have developed indices based on these dimensions, including the Energy Security Price Index (ESPI) by Lefèvre (2010), the Oil Vulnerability Index (OVI) by Gupta (2008), ex-ante and ex-post indicators by Löschel et al. (2010), and the Aggregated Energy Security Performance Indicator (AESPI) by Marchamadol and Kumar (2013), among others. Research on energy security in Small Island Developing States (SIDS) member states (see Table 1 for a list) is of high relevance as they are net energy importers and are intricated by unique geographic, demographic, economic and environmental challenges (Blancard and Hoarau, 2013; UNEP, 2014). SIDS are geographically located in the Atlantic, Indian Ocean, Mediterranean and South China Sea (AIMS),

* Corresponding author.
E-mail address: d.surroop@uom.ac.mu (D. Surroop).

https://doi.org/10.1016/j.jup.2018.06.007
Received 5 September 2017; Received in revised form 12 April 2018; Accepted 13 June 2018
Available online 28 June 2018
0957-1787/ © 2018 Elsevier Ltd. All rights reserved.

Table 1
List of Small Island Developing States (SIDS).[a]
Source: UNEP, 2014

SIDS region	SIDS countries
AIMS	Cape Verde, Comoros, Guinea–Bissau, Maldives, Mauritius, Sao Tome and Principe, Seychelles, [b]Singapore
Caribbean	Antigua and Barbuda, Bahamas, Barbados, Belize, Cuba, Dominica, Dominican Republic, Grenada, Guyana, Haiti, Jamaica, St Kitts and Nevis, St Lucia, St Vincent and Grenadines, Suriname, Trinidad and Tobago
Pacific	Fiji, Kiribati, Marshall Islands, Federated States of Micronesia, Nauru, Palau, Papua New Guinea, Samoa, Solomon Islands, Timor-Leste, Tonga, Tuvalu, Vanuatu

[a] While brief references are made to Papua New Guinea (PNG) and Trinidad & Tobago, the hypothesis elaborated made in this article are less applicable to PNG. PNG and Trinidad & Tobago are an energy exporter, and energy importers and exporters have different dimensions on which their supply of oil to their population depends. Energy security aspects of oil exporters are beyond the scope of this paper.

[b] Singapore is not a developing state but a developed country but is part of the SIDS group. The findings in this study are equally applicable to Singapore as the country share similar environmental and economic challenges as other SIDS members.

Caribbean and Pacific region. The total population of the SIDS is around 61.5 millions with the largest share in the Caribbean which represents 65% followed by Pacific with 18% and AIMS 17% (World Bank, 2017). Research on energy security in SIDS is in its infancy and to our knowledge, this study is the first of its kind to come up with relevant indicators of energy security applicable to island states. So far the World Energy Trilemma 2017 can be used a suitable proxy with Denmark ranked first, and the only SIDS that figured among 125 countries are Singapore (22nd), Mauritius (47th), Dominican Republic (79th), Jamaica (85th) and Trinidad and Tobago (88th) (Leal Filho, 2015; WEC, 2017). It appears to be little progress on indicator development because, so far, little has been done to identify meaningful dimensions on which a stable energy supply on islands depends. The uniqueness of this paper is that, first, it develops a conceptual framing of relevant energy security dimensions for SIDS; and second, based on a review of potential initiatives, it draws out some recommendations of selected strategies and measures to improve energy security in the SIDS context. The article thus contributes by filling a literature gap on energy security and seeks to refocus attention to initiate further research on energy-sector development in SIDS.

2. Methods for data collection

Two methodological approaches were simultaneously used to characterise key dimensions of energy security that are relevant to SIDS. First, a review of present literature based on energy development in SIDS and energy security was conducted. The literature on energy sector of islands was obtained mostly from intergovernmental and think–tank reports. The aim of the literature search was to identify major energy security dimensions and their applicability to small islands. To gauge some arguments, statistical data were collected from various international databases, such as the World Development Indicators of the World Bank, the International Disaster Database from the Centre for Research on the Epidemiology of Disasters (CRED) and the Electricity Database from the International Energy Agency (IEA). Where data were unavailable from these sources, information was retrieved from governmental statistical publications, reports from development banks, regional agencies, and national organisations along with a wide range of peer-reviewed papers. Efforts have been made to gather, as far as possible, the most up–to–date data. Accuracy and authenticity of the data collected were maintained by cross-checking with other statistical reports.

Second, to consolidate the findings of the literature review, a qualitative survey was carried out among energy practitioners in Mauritius, Fiji, Samoa, Vanuatu, Tonga, Tuvalu, and the Federated States of Micronesia. The survey was carried out in 2014 as part of the L^{3}EAP Project (www.project-l3eap.eu), which aims to develop and provide lifelong learning approaches and strengthen local capacities on energy access, security, and efficiency in SIDS. Respondents were chosen purposively and constituted of energy professionals working for non–-governmental organisations (NGOs), the private and public sectors, utility companies, and renewable energy agencies. The survey received 32 respondents from Mauritius and 29 from the Pacific Island Countries (PICs), 61 in total. From PICs, four participants were energy analysts from the Department of Energy, 12 participants were from NGOs, seven participants were from utility companies, and six were from private companies working in the energy domain. In Mauritius, 28 participants were from the power producing companies, three from utility companies and one from a research institution. Most respondents search for securing energy resources as part of their professional responsibility. Respondents with practical knowledge of energy security were sought rather than experts with predominantly theoretical knowledge. A survey in the Caribbean islands was not be conducted in this study, although this research should be generalizable to their experience as well. Respondents were asked basic bio–data information and to give their views on 'energy security' in open-ended questions.

3. Data analysis and discussion

Responses obtained were processed as per Miles and Huberman (1994) and Patton (2002), and as previously applied in Blumer et al. (2015). Recurrent themes from the wide range of views from the survey were used to develop a set of codes which were labelled as (i) import dependency, (ii) energy prices, (iii) climate change and resilience, (iv) governance, (v) energy infrastructure, (vi) equity and (vii) energy efficiency. Some responses, such as one energy expert said: "Energy security has two key dimensions – "reliability and resilience"; "reliability" is attributed to code (i) and "resilience" is attributed to code (iii).

The summary results in Table 2 give the proposed dimensions for a secure energy system in SIDS based on the responses by the survey sample. The percentage recurrence is the number of parameters applicable to a particular code divided by the total number of codes recorded. Most experts claimed *import dependency* and affordable *energy prices* as mandatory parameters for a secure energy system on islands.

Table 2
Survey results from open-ended question and percentage recurrence in responses.

Some keywords and phrases	Dimensions	Percentage
Availability; adequate; reliability; Consistent	Import dependency	46%
Reasonable and affordable prices; economic performance	Energy prices	15%
Clean energy; sustainability; resilience; shocks; withstanding threats; external forces	Climate change and resilience	14%
Management of energy supplies; requirements of a nation	Governance	8%
Generation and distribution system; fuel storage facilities	Energy Infrastructure	6%
Equal distribution; the right; not discriminated against	Equity	6%
Efficient; intelligent use	Energy efficiency	3%

This is not surprising as these two dimensions figure prominently in the literature, where the two terms are known as 'availability' and 'affordability' of energy.

The survey results indicate that *climate change and resilience* are among the top three priority for a secure energy system on islands. Contrasting these results with a study by Ang et al. (2015), who ranked *environment* fifth from a wide range of studies on energy security from developed countries (namely China and Japan), the problem of climate change is more pronounced in SIDS. Other important dimensions identified by experts are governance, energy infrastructure, equal energy distribution, and energy efficiency which are further discussed in the next section.

4. Dimensions of energy security in SIDS

4.1. Import dependency

Based on the survey, the first and most important dimension that characterises energy security in SIDS is import dependency. In general, SIDS are net oil importers. Most energy practitioners agreed that oil import to SIDS countries encompasses all other energy security dimensions, which is spearheaded by high oil consumption. Fig. 1 show the electricity mix in Africa, Caribbean, and Pacific SIDS and as observed over 70% of energy demand for electricity is satisfied by imported fossil fuels. The high dependency on oil exposes SIDS to the direct risks of supply disruptions, and potentially effective solutions (such as source diversification) are not economically feasible in SIDS context. Country-wise, Suriname, Dominica, Fiji, Belize, Cape Verde, and Sao Tomes and Principe have diversified their energy mix by deploying sustainable energy sources, such as wind and hydro, to enhance energy security. However, renewable energy (RE) development in SIDS is still constrained by a number of barriers as discussed by Timilsina and Shah (2016) in their paper. Raghoo et al. (2017b) studied the feasibility of diversifying the energy mix by importing natural gas from neighbouring countries but the possibility of supply disruption remains. Alternatively, source modification can be sought to improve energy security (APERC, 2007). Instead of importing oil from only one country, oil importers can purchase oil from different countries and thus mitigate the risk of supply disruptions (Ang et al., 2015). However, source diversification has its limitations related to geographical distance, political relationships with exporting countries, national energy policies, and the resources required to implement those policies (Vivoda, 2009). Long distances make source diversification 'elusive' for SIDS. In Mauritius, petroleum products are imported from Mangalore Refineries and Petrochemicals Ltd on a 22–day shuttle over 4600 km. Importing oil from different suppliers can increase the cost of oil and thus impact domestic sales.

4.2. Energy prices

The second factor that the survey revealed influencing energy security in SIDS is energy prices. Energy practitioners discussed how energy prices, as an economic dimension, influence energy security. Being small and having a negligible oil demand on the international market, SIDS have less control on the price of goods they import and export and thus are 'price–takers' rather than 'price–setters' (Briguglio, 1995). Since SIDS are sea–locked, they rely extensively on air or maritime transport for imports and exports. Freight costs are unusually high because SIDS lie outside the conventional zone where most ships circumnavigate. This increases oil import expenditures in SIDS. Fig. 2 provides the share of GDP dedicated to oil imports in selected SIDS for which data are available; this fraction is as high as 28% (Palau). Being highly reliant on oil makes SIDS susceptible to oil price shocks. Bacon and Kojima (2008) showed that the changes in economic susceptibility, that is, the variations in the share of GDP accounted by the importation of oil from 1996 to 2006, was 20.2% in Guyana, 14.8% in the Seychelles, 10.1% in the Maldives, and 6.9% in Belize, as compared to 1.0% in Switzerland, 0.8% in Mali, and 2.0% in Uganda. Oil price hikes can give rise to inflation, trade deficits, and high import bills. To counteract the impact of rising oil prices, SIDS seek aid through foreign direct investments or grants or loans from other countries. On a household level, a rise in energy price places stress on the family budget and disproportionately affects those with little resilience to price fluctuations. Businesses might be less competitive, as they face higher input costs but may be unable to easily raise final prices. An associated decline in exports can dis–equilibrate the national balance of payments. Slowing economic growth and concerns about affordability can pressure governments to inject funds for fuel subsidisation. For example, in 2008, the Marshall Islands government injected $8 million to the state-owned utility company for continuous oil procurement (Davies and Sugden, 2010).

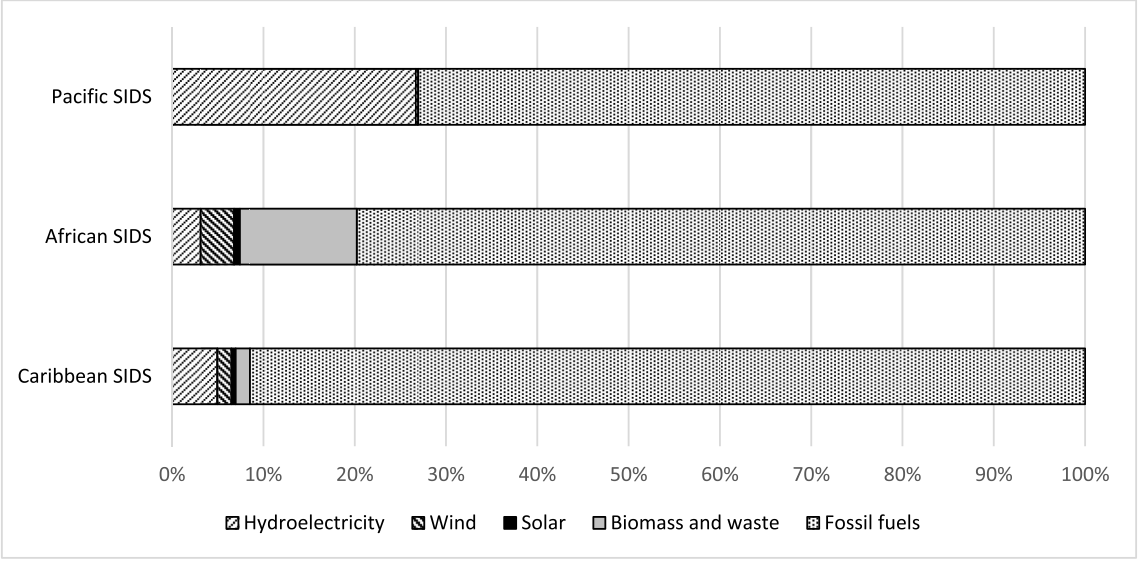

Fig. 1. Electricity generation mix in Pacific, African and Caribbean SIDS, 2015.
Source: authors' illustration from data from EIA, 2015

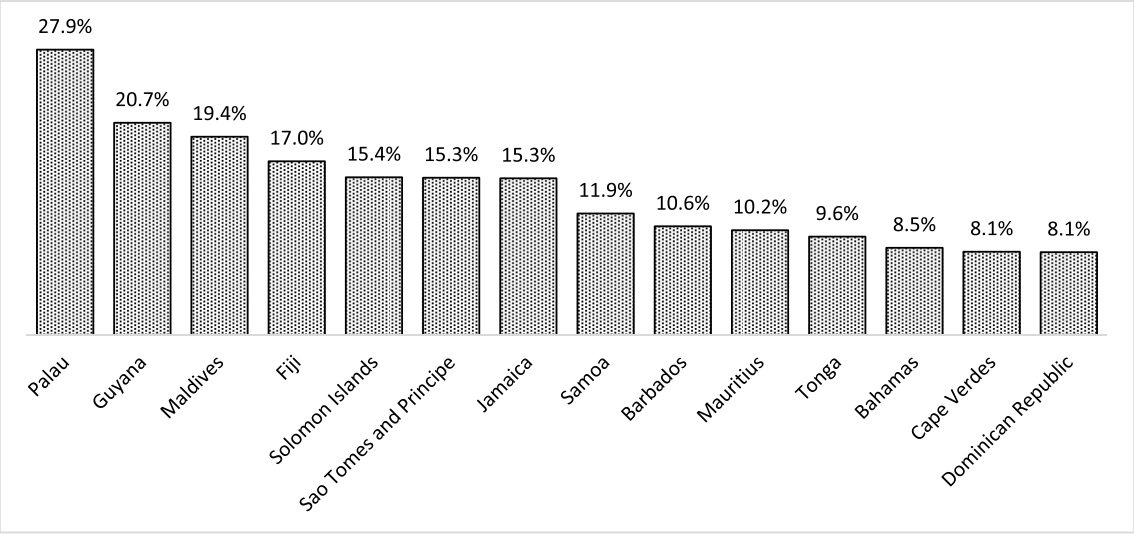

Fig. 2. Percentage share of GDP on oil imports for selected SIDS, 2013.
Source: World Development Indicators (2013), World Bank; authors' calculations

4.3. Climate change and resilience

Resilience is the ability to make extra preparation and to adapt to the changing environment and avoid or address disruptions the earliest (President Policy Directive 21, 2013). Our experts aimed their attention to the disastrous effects of climate change on island nations and the lack of capacity to mitigate and adapt. An energy system cannot be sustainable in the face of negative environmental externalities, such as overexploitation of natural resources, air pollution, and climate change. Climate change is known to destabilise naturally–occurring cycles and to be an initiator of more frequent and severe natural calamities, such as droughts, floods, tropical cyclones, and tsunamis. Cyclones are formed by the interaction of the atmosphere and sea and are capable of causing massive destruction of island infrastructure, communication services, and settlements. (UNEP, 2014). The damage caused by natural disasters can even surpass a country's GDP, resulting in a major economic set–back (Fig. 3). In Haiti, for example, the total cost of damage from natural disasters from 2000 to 2014 (including the January 2010 earthquake) were 118.0% of its GDP; for the same period in Samoa, the total cost amounted to 41.8% of its GDP; and in the Dominican Republic (DR), the total cost was about 0.5% of its GDP. In SIDS, experts consider climate change as an element of energy security. Previous studies have pointed to the synergies of climate change, energy access, renewable energy, and air pollution with national energy security policies (Bazilian et al., 2011; Bang, 2010; Bollen et al., 2010; King and Gulledge, 2013; Rogers–Hayden et al., 2011; Shadman et al., 2016; van Vliet et al., 2012). These studies highlight the need to implement climate change mitigations measures to build resilience and maintain energy security.

For SIDS, disruption does not only mean disruption from changing environmental conditions. Risk management (Roege et al., 2014) not only includes withstanding climatic conditions but also other shocks, such as terrorism, accidents, sabotage, theft, and import-supply risks, too (Yeeles and Akporiaye, 2016). As put forward in Goldthau and Sovacool (2012), potential approaches to resilience in SIDS energy systems are still unimplemented, leaving them vulnerable to these external shocks. An example is the threat of attacks by Somalian pirates on oil tankers destined to countries in the Indian Ocean, where there is

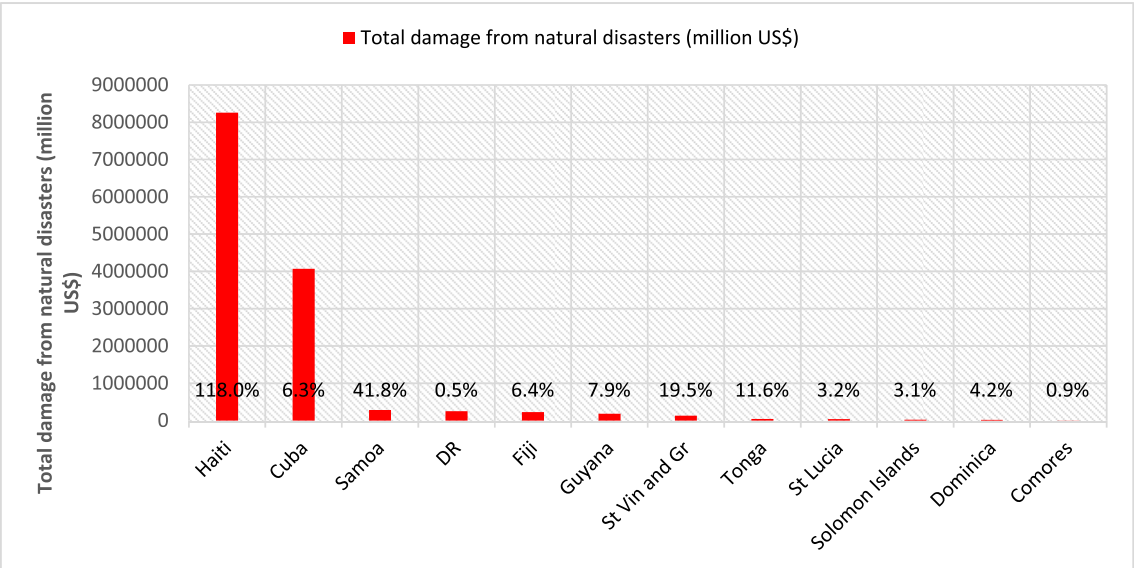

Fig. 3. Cumulative total cost of damages from natural disasters for the period 2000–2014 in some selected SIDS and the percentage share of GDP it accounts for.
Sources: World Development Indicators (2014), World Bank; International Disaster Database; authors' calculations

still room for improvement despite measures taken.

4.4. Governance

The survey revealed, at the fourth position, the issue of 'energy governance' in SIDS which is critical in devising and coordinating policies to address energy security issues. Sound and forward-looking governments can establish conducive energy policies to mitigate short-term oil disruptions and build robust infrastructure to maintain long-term energy supply (Ang et al., 2015). However, in practice, energy governance in most SIDS is 'flawed'. As such, little effort is made for the phasing out of distortionary subsidisation policies – for example, in Fiji, Mauritius, Samoa, Trinidad & Tobago among others, the government and other development partners have provided subsidies to make energy affordable to households. However, these subsidies are not meant tested and thus households with high income benefits from them. On a macroeconomic level, this constitutes an economic inefficiency and significant investment from the part of the government which is not necessary. The most alarming issue is that there is no governmental plan in most SIDS for the phasing out of these subsidies and 'unlock' funding for the mitigation of energy security effects. On the other side, SIDS benefit from millions of dollars from international aid – Pacific SIDS only benefitted from US$1.49 billions for the period 1970–2014 (Keeley, 2017) – but as the donor funding is intended to create an enabling environment for the development of RE and mitigation of energy security, they are having adverse effects to enhancing an enabling investment environment (Keeley, 2017). For all of these ineffective fiscal policies, governments are responsible for their removal but it appears that too little is being done. From the survey, the importance of good governance as a dimension of energy security was revealed and the critical role that government has to play to increase resilience towards energy security highlighted. Good governance is therefore necessary to formulate and implement effective policies.

4.5. Energy infrastructure

The fifth dimension of energy security was energy infrastructure. Energy infrastructure refers to all components of the energy supply chain, which in the case of SIDS refers to transport by sea, disembarkment of oil, delivery of a primary energy source, or conversion to a secondary energy source (electricity) and its transmission and distribution of primary energy sources. Energy infrastructure for oil importing countries includes high-efficiency refineries, suitable oil tankers, adequate berthing and ports, and oil tanks for oil storage. Ports need to be equipped with proper berthing lengths, quay apron areas, and road access. Regular maintenance must be done to ensure that port infrastructure provides the intended function. Also, maritime accidents occurring from either sinking ships, collisions of ships, or collision with port infrastructure can narrow approach channels and obstruct anchorages and port areas in some SIDS (UNCTAD, 2014). Since most SIDS have only one berth, damage to it can hinder imports and exports of goods. This is a direct threat to a country's energy security, as port infrastructure is the key component of the oil supply chain. Poor maintenance and inadequate financial and technical resources can cause accidents and oil spills. The Asian Development Bank (2007) identifies some serious issues with port infrastructure in the Pacific countries, highlighting that Palau port, which dates back to World War II, should be overhauled for continuous operation. Oil storage tanks must be robust enough to resist natural disasters.

Efficient infrastructure, including cables and transformers and other equipment for electricity transmission and distribution, is also vital to maintaining the security of electricity service. In Haiti for instance, 60% of electricity supplied on the grid is lost in transmission and distribution (World Bank, 2014), 48% in Comoros and 47% in Guinea–Bissau (Surroop and Raghoo, 2018) with substantial economic consequences. Though these line losses cannot be eliminated, they can be minimized by regular maintenance and improvements in power factors by other measures. The March 2011 nuclear catastrophe in Japan and the subsequent huge trade deficits the disaster created for the country (Vivoda, 2012) directly indicate the need for proper planning of electricity generating infrastructure to withstand disasters of any magnitude. The devastation to Puerto Rico's electrical system following the 2017 hurricane provides another striking example.

4.6. Equity

An energy system cannot be regarded as secure if there exists within the system an unequal distribution of energy, where some areas have access to energy while others do not. The relation between equity and energy security can be discussed first with respect to oil supply, and second with respect to the supply of secondary energy (electricity). The first inequity lies in the unequal distribution of oil among energy importers and exporters. The Asian–Pacific, European and North–American countries consume 80% of the world's oil but control only 10% of the world's oil reserves. Countries of the former Soviet Union, Africa, Latin America, and the Middle East control 90% of the global oil reserves but consume only 20% of the resource (BP, 2008 cited in Vivoda, 2009). The global energy market is, therefore, quite unbalanced. At the same time, the sheer size and pace of growth of China and India are changing the global energy market with an ever-increasing appetite for oil (Vivoda, 2010). China has planned energy strategies, including import diversification (Wu, 2014), to take in more oil, which will result in greater competition for oil on the market. As the experts discussed, SIDS fall far behind and are often ignored due to their relatively small share of the world's oil consumption; despite their high dependence on oil, SIDS are not powerful enough to compete with superpowers for oil resources.

The second inequity concerns the domestic supply of energy in the form of electricity, which is rarely viewed as equitable because of variations in reliability across regions; in villages and rural areas, access to electricity is usually low. In the PICs, for instance, the electrification rate (the percentage of the population having access to electricity) varies from 14% in the Solomon Islands and 17% in Vanuatu, as compared to 89% in Fiji and 99% in Samoa (Dornan, 2014). The inability to provide equitable access to energy aggravates poverty and deepens the rich-poor gap in developing countries.

4.7. Energy efficiency

Survey results also highlight the importance of energy efficiency and conservation in maintaining security of energy supply. Energy security and energy efficiency are closely linked as reported by the World Bank (2005) and ESCAP (2008). The implementation of energy efficiency programmes such as shifting to more energy efficient technologies entails a reduction in overall energy demand (whether in terms of oil or electricity) of a particular region, thus alleviating the pressure on governmental authorities to supply more energy. The government will thus have more funds to inject in other priority areas for better development of the country. Energy efficiency is also an effective tool to mitigate global greenhouse gas emissions from energy production and to improve oil security by mitigating oil price hikes. Recognising the potential of energy efficiency, some SIDS have implemented some energy efficient programmes, the most common ones being energy labelling of household appliances and substituting incandescent lighting for more efficient light bulbs. In Mauritius, from August 2008 to April 2009, one million incandescent lamps was replaced by Compact Fluorescent Light (CFL) yielding 12.5 GWh of electricity saved during peak hours (CEB, 2013). Same situation in Cuba where nearly all bulbs were replaced by was replaced by CFL (Guevara–Stone, 2009). However, beyond this point, there has been very little consideration given to energy efficiency in SIDS. Since few of our experts discussed the influence of energy efficiency in strengthening energy security – hence

ranked seventh – it can be, intuitively taken that the some experts underlie the potential of energy efficiency when discussing energy security issues. A more comprehensive discussion in given in the next section.

5. Potential strategies for improving energy security in SIDS

An account of different practical initiatives that can be adopted to enhance the security of energy supply in oil importing SIDS is given here. Before any policy is passed or initiative is undertaken, a comprehensive feasibility study should be conducted to identify potential benefits, costs, and flaws in the proposed strategy. Evaluating the applicability of each strategy in the context of SIDS is beyond the scope of this paper.

5.1. Demand-side management (DSM) and energy efficiency

As previously pointed out by Narula and Reddy (2016), the intensive focus on 'security of energy supply' can lead to confusion about the role of demand-side management and energy efficiency in enhancing energy security. DSM consists of a set of activities that can be used to monitor and alters the end use of energy. Efficiency improvements on the customer's side ultimately help lower emissions and supply needs. Benefits of DSM practices and relevant management techniques are thoroughly discussed in Strbac (2008). For SIDS, DSM is the least costly option to reduce dependency on oil imports.

Energy efficient measures can be adopted in industries, transport, and buildings. For industries that rely on oil to power equipment, sound maintenance practices, energy audits, and the use of efficient machinery in plants can decrease fuel input. Simple household measures such as proper tuning of air conditioners, switching off electrical appliances when not in use, or using more efficient lamps for lighting can dramatically cut electricity use and emissions from the use of oil. In the transportation sector, which is the most oil-consuming sector, proper road planning such as street layouts, pavement improvements, and other infrastructural measures can help to reduce oil use by vehicles. Using hybrid cars, prioritising walking and cycling for short distances, reducing travel speed for vehicles, and providing mass transport are also potential initiatives to curb oil intake (Sathaye et al., 2007). Education and training is also lacking in SIDS and should be prioritised (Raghoo et al., 2017a). Some efficient energy practices require little or no cost at all, and it is the combined small actions by millions of islanders that can reduce dependency on imported fossil fuels.

As an example of an energy efficiency initiative, the proposed Sea Water Air Conditioning Project (SWAC) in Mauritius to use seawater pumped from the ocean to replace air conditioning in buildings in the capital city is a major project expected to replace the equivalent of 30 MW of electrical power by an ocean-derived cooling system (REN21, 2015). With regards to the different energy efficiency measures and policies available (see IEA, 2015), it is essential to implement an action plan based on finding, environmental, demographic, and other territorial data to assess which measure or policy is best–suited for a particular region (Sanseverino et al., 2014).

5.2. Maintenance of Strategic Petroleum Reserves (SPR)

Strategic Petroleum Reserves (SPR), or stockpiling, is the storage of petroleum to be used during short-term oil supply disruptions or in emergency situations as may be caused by natural disasters. SPR is not a recent approach to tackle oil security problems (e.g., see Balas, 1979) but since much of the academic literature is focussed on the United States, China, or IEA-member countries, applications within SIDS remains understudied. While setting up an SPR on small islands can be debated due to numerous factors, such as optimal size of the reserve, financial, and institutional issues, and drawdown decision-making processes; it nevertheless represents a viable means to plan for anticipated oil scarcity. Benefits of having SPR are primarily economic. First, opportunities exist where the government can buy oil at a lower price and sell it to customers at a higher price. Second, SPR can dampen oil price hikes during disruptions, thereby limiting economic setback and panic buying. This also allows enough time to find alternative solutions to alleviate oil supply shortages (Paik et al., 1999). In the exceptional case of SIDS, frequent natural catastrophes can paralyse port activities or make it difficult for ships to deliver oil. In these cases, reserves from the SPR can be drawn to satisfy energy needs rather than attempting to disembark oil from ships under poor meteorological conditions. Finally, it can alleviate politically or economically motivated oil disruptions (Taylor and van Doren, 2005). Paik et al. (1999) discussed the available technologies for oil storage and their cost implications. Others (Meng et al., 2016; Zhou et al., 2016; Zhu et al., 2012) have focussed on optimal sizing of oil reserves by stochastic modelling.

Leiby et al. (2002) argued that the cost that small economies must bear to set up oil stockpiles do not justify the benefits accrued. However, benefits derived from stockpiling are additive and thus, a reserve could be jointly shared by a collection of nearby islands, especially in the Caribbean and Pacific regions. Stockpiling oil can thus be used as a tool for diplomacy and collaboration.

5.3. Energy mix diversification

SIDS are blessed with a substantial RE potential whose exploitation and development are strongly encouraged to diversify the energy mix and reduce dependency on oil imports. Many efforts have already been devoted to expanding sustainable sources of energy in SIDS. Most of the SIDS have established RE development goals by a certain time period (with the exception of Papua New Guinea) (Dornan, 2014). Mauritius for instance, has come up with a long-term energy strategic plan and is expected to generate 8% of its electricity needs by wind, 6% by hydro, 2% by solar PV, and 2% by geothermal energy by 2025 from existing 3% hydro and 0.2% solar with limited work geothermal energy so far (CSO, 2015; MEPU, 2009; Surroop and Raghoo, 2017; Wolf et al., 2016). A wind farm project is underway, but there is still a long way to go to achieve targets. Table 3 demonstrates the RE potential for some Caribbean SIDS.

There is no doubt that SIDS are blessed with abundant RE sources (Shirley and Kammen, 2013; Timilsina and Shah, 2016; Prasad et al., 2017). Solar, wind, biomass, and hydroelectricity seem the most preferred RE resources because of the current mature status of these technologies and their cost–competitiveness with fossil-fuel technologies. However, there are some financial and institutional barriers that small islands face in achieving RE targets. Although SIDS receive some financial aid (known as Official Development Assistance, ODA) (Niles and Lloyd, 2013), SIDS governments are unable to invest heavily in the energy sector as they must also invest in education, water, food security, and poverty alleviation. Timilsina and Shah (2016)

Table 3
Renewable energy potential in Caribbean SIDS.
Source: Nexant, 2010

Caribbean islands	Wind (MW)	Geothermal (MW)	Hydro (MW)	Solar PV (MW)
Antigua and Barbuda	400	–	–	27
Barbados	10	–	–	26
Dominica	–	100	8	45
Dominican Republic	3200	–	210	2899
Grenada	11	499	–	21
Haiti	10	–	50	1654
Jamaica	70	–	22	650
St Kitts and Nevis	5	300	–	16

comprehensively described the barriers and 'policy enablers' for more RE development in SIDS. It is difficult to access financial resources from foreign investment due to significant challenges (Dornan, 2015), including a lack of incentives for private-sector participation, diseconomies of scale, a thin financial base, and a lack of governance capacity. However, as demonstrated by Dornan and Jotzo (2015), who applied portfolio theory to SIDS, found that energy efficiency measures combined with renewable technologies help reduce the cost of energy production, which in turn reduces financial risk. This is in contrast to other countries facing a cost–risk trade–off from RE integration. Ultimately, to drive more RE within SIDS, it is important to establish economic incentives, including incentives for the private sector, to participate in developing more sustainable resources. An example is the Turtle Beach Resort in Barbados, where French Polynesian government gave a 35% tax credit to replace electric water heating powered by diesel generators with solar water heating, yielding $1.48 million in energy savings and 655 tons of carbon emissions avoided from 1997 to 2013 (IRENA, 2014). Another policy instrument is a feed-in tariff (FIT), which guarantees investors compensation, including a return on investment, for electricity generated from green sources (Jacobs et al., 2013). Gaps in technical and educational skills of islanders to adopt RE technologies can be addressed by training and capacity building.

6. Conclusions

Energy security is fundamental for the sustainable socio-economic development of SIDS. Since SIDS are not energy self–sufficient and rely mostly on fossil fuels for meeting their energy needs, the security of energy supplies is of utmost importance. In this article, an attempt was made to identify potential determinants of energy security for SIDS. The seven dimensions identified are regarded as key to ensuring a more secure energy supply. Hence, monitoring the seven dimensions as revealed by this paper can facilitate the tasks of policymakers to see the progress in ensuring security of energy supply in SIDS. Based on the conceptual framework presented in this paper, more research is needed to develop energy security indicators and indices specific to SIDS. The dimensions proposed, coupled with the special vulnerabilities faced by islands, can be considered to gauge energy security performance and thus improve future energy policies and planning. Most strategies to enhance energy security are underexploited as well as understudied, indicating further research opportunities. Given the importance of energy efficiency to energy security, raising awareness and communicating the advantages of efficient production and use of energy is especially needed for small island nations.

Acknowledgments

This paper was produced in line with the EDULINK/European Union (EU) (FED/2013/320-080) funded project L^{3}EAP. The views and opinions in this paper belong entirely to the authors and cannot, under any circumstances be taken as those of the European Union. The authors are also grateful to the anonymous reviewers and Janice Beecher who have significantly contributed to improve the quality of this paper.

References

Ang, B.W., Choong, W.L., Ng, T.S., 2015. Energy security: definitions, dimensions and indexes. Renew. Sustain. Energy Rev. 42, 1077–1093.
APERC, 2007. A Quest for Energy Security in the 21st century. Asian Pacific Energy Research Centre, Tokyo, Japan.
Asif, M., Muneer, T., 2007. Energy supply, its demand and security issues for developed and emerging economies. Renew. Sustain. Energy Rev. 11, 1388–1413.
Bacon, R., Kojima, M., 2008. Vulnerability to Oil Prices Increases: a Decomposition Analysis of 161 Countries. Extractive Series and Development Industries 1. World Bank, Washington DC.
Balas, E., 1979. The Strategic Petroleum Reserve: How Large Should it Be? Carnegie-Mellon University, Design Research Center, Pittsburgh.
Bang, G., 2010. Energy security and climate change concerns: triggers for energy policy change in the United States? Energy Pol. 38, 1645–1653.
Bazilian, M., Hobbs, B.F., Blyth, W., MacGill, I., Howells, M., 2011. Interactions between energy security and climate change: a focus on developing countries. Energy Pol. 39, 3750–3756.
Blancard, S., Hoarau, J.F., 2013. A new sustainable human development indicator for small island developing states: a reappraisal from data envelopment analysis. Econ. Modell. 30, 623–635.
Blumer, Y.B., Moser, C., Patt, A., Seidl, R., 2015. The precarious consensus on the importance of energy security: contrasting views between Swiss energy users and experts. Renew. Sustain. Energy Rev. 52, 927–936.
Bollen, J., Hers, S., van der Zwaan, B., 2010. An integrated assessment of climate change, air pollution, and energy security policy. Energy Pol. 38, 4021–4030.
BP (British Petroleum), June 2016. BP Statistical Review of World Energy. British Petroleum.
Briguglio, l., 1995. Small islands developing states and the economic vulnerabilities. World Dev. 23 (9), 1615–1632.
Cao, W., Bluth, C., 2012. Challenges and countermeasures of China's energy security. Energy Pol. 53 581–383.
CEB, 2013. Integrated Electricity Plan 2013 – 2022. Central Electricity Board.
Cherp, A., Jewell, J., 2011. The three perspectives of energy security: intellectual history, disciplinary roots and the potential for integration. Curr. Opin. Environ. Sustain. 3, 202–212.
Chester, L., 2010. Conceptualising energy security and making explicit its polysemic nature. Energy Pol. 38, 887–895.
Chuang, M.C., Ma, H.W., 2013. An assessment of Taiwan's energy policy using multi-–dimensional energy security indicators. Renew. Sustain. Energy Rev. 17, 301–311.
CRED (Centre for Research on the Epidemiology of Disasters). Available on http://www.emdat.be/database (Accessed on 15 September 16).
CSO, 2015. Digest of Energy and Water Statistics, 2014. Central Statistics Office, Mauritius.
Davies, M., Sugden, C., 2010. Microeconomic Impacts of Energy Prices in the Pacific. Pacific Financial Technical Assistance Centre Regional Papers, Suva, Fiji.
Dornan, M., 2014. Access to electricity in small island developing states of the pacific: issues and challenges. Renew. Sustain. Energy Rev. 31, 726–735.
Dornan, M., 2015. Renewable energy development in small island developing states of the pacific. Resources 4, 490–506.
Dornan, M., Jotzo, F., 2015. Renewable technologies and risk mitigation in small island developing states: Fiji's electricity sector. Renew. Sustain. Energy Rev. 48, 35–48.
Ebinger, C.K., 2011. The meaning of energy security depends on who you are, retrieved on February 01. 2016. http://www.brookings.edu/research/opinions/2011/10/10-energy-security-ebinger.
ESCAP, 2008. Energy Security and Sustainable Development in Asia and the Pacific. United Nations Economic and Social Commission for Asia Pacific, Bangkok.
Goldthau, A., Sovacool, B.K., 2012. The uniqueness of the energy security, justice and governance problem. Energy Pol. 41, 232–240.
Guevara–Stone, L., 2009. La Revolucion Energetica: Cuba's Energy Revolution 2 Renewable Energy World.
Gupta, E., 2008. Oil–vulnerability index of oil–importing countries. Energy Pol. 3, 1195–1211.
Hughes, L., 2012. A generic framework for the description and analysis of energy security in an energy system. Energy Pol. 42, 221–231.
IEA, 2015. Regional Energy Efficiency Policy Recommendations – Latin America and the Caribbean. International Energy Agency, Paris.
IRENA, 2014. Renewable Energy Opportunities for Islands Tourism. International Renewable Energy Agency, Bonn, Germany.
Jacobs, D., Marzolf, N., Paredes, J.P., Flynn, H., Becker–Brick, Solano–Peralta, M., Rickerson, W., 2013. Analysis of renewable energy incentives in the Latin America and Caribbean region: the feed–in tariff case. Energy Pol. 60, 601–610.
Keeley, A.R., 2017. Renewable energy in Pacific Small Island Developing States: the role of international aid and the enabling environment from donor's perspectives. J. Clean. Prod. 146, 29–36.
King, M.D., Gulledge, J., 2013. The climate change and energy security nexus. Fletcher Forum World Aff. 37 (2), 25–44.
Kucharski, J., Unesaki, H., 2015. A policy–oriented approach to energy security. Procedia Environ. Sci. 28, 27–36.
Leal Filho, W., Voudouris, V. (Eds.), 2013. Global Energy Policy and Security. Springer, London.
Leal Filho, W., 2015. World energy outlook emphasises the need for low-carbon energy developments. Int. J. Clim. Change Strat. Manag. 7 (4), 2–3.
Lefèvre, N., 2010. Measuring the energy supply implications of fossil fuel resource concentration. Energy Pol. 38, 1635–1644.
Leiby, P.N., Bowman, D., Jones, D.W., 2002. Improving Energy Security through an international cooperative approach to emergency oil stockpiling. In: Proceedings of the 25th Annual IAEE International Conference, June 26–29, Aberdeen, Scotland.
Löschel, A., Moslener, U., Rubbelke, D.T.G., 2010. Indicators of energy security in industrialised countries. Energy Pol. 38, 1665–1671.
Martchamadol, J., Kumar, S., 2013. An aggregated energy security performance indicator. Appl. Energy 103, 653–670.
Meng, F.Y., Zhou, P., Bai, Y., Zhiu, D.Q., Ju, K.Y., 2016. Desirable policies of a strategic petroleum server I coping with disruption risk: a Markov decision process approach. Comput. Oper. Res. 66, 58–66.
MEPU, 2009. Long Term Energy Strategy 2009 – 2025. Ministry of Energy and Public Utilities, Mauritius.
Miles, M.B., Huberman, A.M., 1994. Qualitative Data Analysis: a Sourcebook of New Methods, second ed. Sage Publications, Inc. USA, Thousand Oaks, CA.
Misila, p., Winyuchakrit, P., Lemmeechockchai, B., 2015. Roadmap to Thailand's

nationally appropriate mitigation (NAMAs) by 2020: energy security and Co–Benefit aspects. Energy Procedia 79, 590–595.
Narula, K., Reddy, S.B., 2015. Three blind men and an elephant: the case of energy indices to measure energy security and energy sustainability. Inside Energy 80, 148–158.
Narula, K., Reddy, S.B., 2016. A SES (sustainable energy security) index for developing countries. Inside Energy 94, 326–343.
Nexant, 2010. Caribbean Regional Electricity Generation, Interconnection and Fuels Supply Strategy, Final Report. . www.caricom.org/jsp/community_organs/energy_programme/electricity_gifs_strategy_final_report.pdf, Accessed date: 8 March 2016.
Niles, K., Lloyd, B., 2013. Small Island developing states (SIDS) & energy aid: impacts on the energy sector in the Caribbean and Pacific. Energy. Sustain. Dev. 17, 521–530.
Paik, I., Leiby, P., Jones, D., Yokobori, K., Bowman, D., 1999. Strategic Oil stocks in the APEC region. In: Proceedings of the 22nd IAEE Annual International Conference. International Association for Energy Economists, Italy.
Patton, M.Q., 2002. Qualitative Evaluation and Research Method, third ed. Sage Publications, Inc. USA, Thousand Oaks.
Phdungsilp, A., 2015. Assessing energy security performance in Thailand under different scenarios and policy implication. Energy Procedia 79, 982–987.
Prasad, R.D., Bansal, R.C., Raturi, A., 2017. A review of Fiji's energy situation: challenges and strategies as a small island developing state. Renew. Sustain. Energy Rev. 75, 278–292.
Presidency Policy Directive 21, 2013. https://www.whitehouse.gov/the-press-office/2013/02/12/presidential-policy-directive-critical-infrastructure-security-and-resil, (Accessed on 3 March, 2016).
Raghoo, P., Jeetah, P., Surroop, D., 2017a. Lifelong learning (LLL) for energy practitioners in Small Island Developing States (SIDS): the pivotal role of education in energy efficiency and demand side management. In: Leal Filho, W. (Ed.), Climate Change Adaptation in Pacific Countries, Climate Change Management. Springer.
Raghoo, P., Surroop, D., Wolf, F., 2017b. Natural gas to improve energy security in Small Island Developing Countries: a techno-economic analysis. Dev. Eng. 2, 92–98.
REN21, 2015. SADC Renewable Energy and Energy Efficiency: Status Report. REN21 Secretariat, Paris.
Rentschler, J.E., 2013. Oil price Volatility, Economic Growth and the Hedging Role of Renewable Energies. Policy Research Working Paper 6603. World Bank, Washington DC.
Roege, P.E., Collier, Z.A., Mancillas, J., McDonagh, J.A., Linkov, I., 2014. Metrics for energy resilience. Energy Pol. 72, 249–256.
Rogers–Hayden, T., Lorenzoni, I., Hatton, F., 2011. 'Energy security' and 'climate change': constructing UK energy discursive realities. Global Environ. Change 21, 134–142.
Rosen, M.A., 2009. Key energy-related steps in addressing climate change. Int. J. Clim. Change Strat. Manag. 1, 31–41.
Sanseverino, E.R., Sanseverino, R.R., Favuzza, S., Vaccaro, V., 2014. Near zero energy islands in the Mediterranean: supporting policies and local obstacles. Energy Pol. 66, 592–602.
Sathaye, J.A., Cocklin, C., Heller, T., Lecocq, F., Llanes–Regueiro, J., Pan, J., Petschel–Held, G., Robinson, J., Rayner, S., Schaeffer, R., Sokona, Y., Swart, R., Winkler, H., 2007. Sustainable development and mitigation. In: Metz, B., Davidson, O.R., Bosch, P.R., Meyer, L.a. (Eds.), Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, UK, NY.
Selvakkumaran, S., Limmeechokchai, B., 2013. Energy security and co–benefits of energy efficiency improvements in three Asian countries. Renew. Sustain. Energy Rev. 20, 491–503.
Shadman, F., Sadeghipour, S., Moghavvemi, M., Saidur, R., 2016. Drought and energy security in key ASEAN countries. Renew. Sustain. Energy Rev. 53, 50–58.
Shirley, R., Kammen, D., 2013. Renewable energy sector development in the Caribbean: current trends and lessons om history. Energy Pol. 57, 244–252.
Sovacool, B.K., Mukherjee, I., 2011. Conceptualizing and measuring energy security: a synthesized approach. Inside Energy 36, 5343–5355.
Sovacool, B.K., 2011. Evaluating energy security in the Asia Pacific: towards a more comprehensive approach. Energy Pol. 39, 7472–7479.
Strbac, G., 2008. Demand side management: benefits and challenges. Energy Pol. 36, 4419–4426.
Stringer, K.D., 2008. Energy Security: applying a portfolio approach. Baltic Secur. Defense Rev. 10, 121–142.
Surroop, D., Raghoo, P., 2017. Energy landscape on Mauritius. Renew. Sustain. Energy Rev. 73, 688–694.
Surroop, D., Raghoo, P., 2018. Renewable energy to improve energy situation in African island states. Renew. Sustain. Energy Rev. 88, 176–183.
Taylor, J., van Doren, P., 2005. The Case against Strategic Petroleum Reserve. Policy Analysis, No. 555. Cato Institute.
Timilsina, G.R., Shah, K.U., 2016. Filling the gaps: policy supports and interventions for scaling up renewable energy development in Small Island Developing States. Energy Pol. 98, 653–662.
UNCTAD, 2014. Closing the Distance: Partnerships for Sustainable and Resilient Transport Systems in SIDS. In: United Nations Conference on Trade and Development, Geneva.
UNEP, 2014. Global environment outlook, small island developing states. United Nations Environmental Programme, Nairobi, Kenya.
van Vliet, O., Krey, V., mcCollum, D., Pachauri, S., Nagai, Y., Rao, S., Riahi, K., 2012. Synergies in the Asian energy system: climate change, energy security, energy access and air pollution. Energy Econ. 34, 5470–5480.
Vivoda, V., 2009. Diversification of oil imports sources and energy security: a key strategy or an elusive objective? Energy Pol. 37, 4615–4623.
Vivoda, V., 2010. Evaluating energy security in the Asia–Pacific region. A novel methodological approach. Energy Pol. 38, 5258–5263.
Vivoda, V., 2012. Japan's energy security predicament post–Fukushima. Energy Pol. 46, 135–143.
von Hippel, D., Suzuki, T., Williams, J.H., Savage, T., Hayes, P., 2011. Energy security and sustainability in Northeast Asia. Energy Pol. 39, 6719–6730.
Winzer, C., 2012. Conceptualizing energy security. Energy Pol. 46, 36–48.
Wolf, F., Surroop, D., Singh, A., Leal, F., 2016. Energy access and security strategies in small island developing states. Energy Pol. 98, 663–673.
World Bank, 2005. Energy Security Issues. The World Bank Group, Moscow – Washington DC.
World Bank, 2017. World Development Indicators – the Little Green Data Book. Washington DC. .
World Bank, 2014. World Development Indicators. http://databank.worldbank.org/data/reports.aspx?source=world-development-indicators.
World Development Indicators, 2013. World Bank. Available on. http://data.worldbank.org/indicator, Accessed date: 15 September 2016.
World Development Indicators, 2014. World Bank. Available on. http://data.worldbank.org/indicator, Accessed date: 17 December 2017.
World Energy Council, 2017. World Energy Trilemma Index 2017 – Monitoring Sustainability of National Energy Systems, UK.
Wu, K., 2014. China's energy security: oil and gas. Energy Pol. 73, 4–11.
Yeeles, A., Akporiaye, A., 2016. Risk and resilience in the Nigerian oil sector: the economic effects of pipeline sabotage and theft. Energy Pol. 88, 187–196.
Zhou, P., Bai, Y., Meng, F., Tian, L., 2016. Desirable strategic petroleum reserves policies in response to supply uncertainty: a stochastic analysis. Appl. Energy 162, 1523–1529.
Zhu, Z., Liu, L., Wang, J., 2012. Optimization of China's strategic petroleum reserve policy: a Markovian decision approach. Comput. Ind. Eng. 63, 626–633.